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Title: A Non-invasive beam size diagnostic for ARIA

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A Non-Invasive Beam Size Diagnostic for ARIA

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Diagnostics for ARIA should include non-invasive measurements of beam size for tuning to optimum radiographic performance.

- Beam size at the accelerator exit is one of the initial conditions required for rational design of downstream and final focus tunes.
- Beam size coupled with BPM data provides a measurement of the beam ellipticity, which could distort the radiographic spot.
- Continuous monitoring of the beam size at the accelerator exit can provide early warning of tune shifts due to injector problems or component malfunctions.

The beam size can be measured non- invasively using a diamagnetic loop

- Beam diamagnetism reduces Bz inside of the beam.
- Flux conservation inside beam pipe requires that flux outside of beam is increased by same amount as flux excluded from the beam.
- Diamagnetic loop can detect the increase in flux, which can be related to the beam size.
- Difficult measurement, but can be done.

Diamagnetic loop theory is well developed, and experiments have been successful.

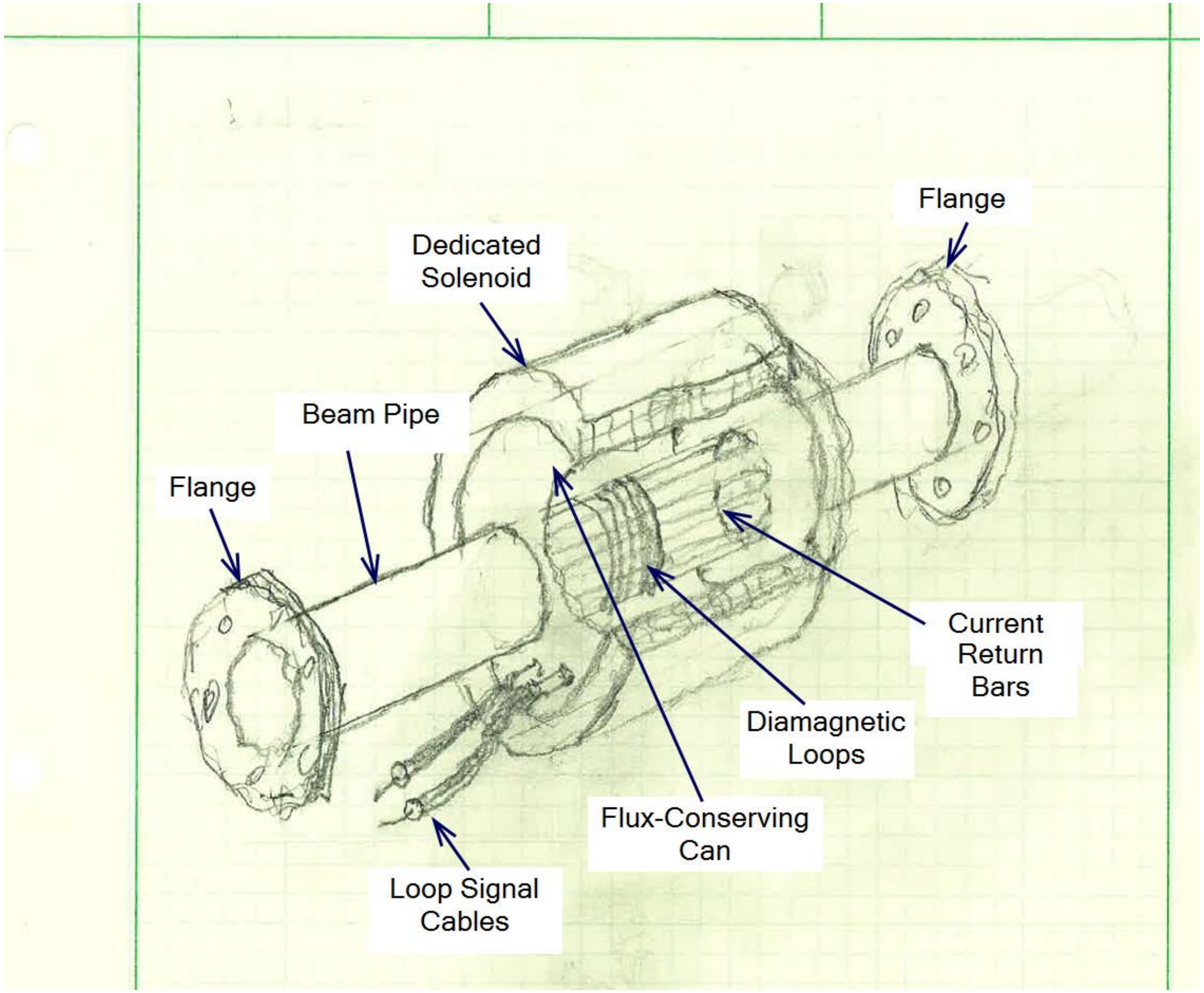
- W. Nexsen, “A non-interfering beam radius diagnostic,” LLNL Report UCRL-JC-108211, 1991
- C. Ekdahl, “Noninvasive measurement of electro-beam size with diamagnetic loops,” Rev. Sci. Instrum., vol. 72, 2001, pp. 2909-2914
- W. Nexsen, et al., “Reconstruction of FXR beam conditions,” 2001 Particle Accelerator Conference, 2001, pp. 2383-2385
- W. Nexsen, eta al., “DML and foil measurements of ATA beam radius,” LLNL Report UCRL-TR-213325, 2005

The single major problem encountered in making these measurements on LIAs has been location.

- Available locations in accelerators have been in weak fringe field of transport solenoids.
- Loops are required to be too close to beam pipe to be effective.
- Locations are not suitable for multi-turn loops.

- These problems can be solved by using a standalone design with a small, dedicated solenoid for the bias field.

A dedicated station for these measurements on ARIA can be easily inserted into either of the DARHT accelerator beam lines for testing.



Diagnostic sensitivity depends on dimensions and bias field strength.

- **Single loop signal:**

$$V_{loop} = \pi R^2_{rms(beam)} B_z \frac{dI_b / dt}{17\beta\gamma \mathrm{kA}} \left[1 - \frac{R^2_{loop}}{R^2_{wall}} \right]$$

- **Signal is proportional to the area between the loop and the outer wall,** $\pi R^2_{wall} - \pi R^2_{loop}$

- **Signal is proportional to bias field, *B_z*.**

The ARIA design would provide high-amplitude signals for accurate beam size measurements

- **Example:**

B_z = 100 G, R_{loop} = 3”, R_{wall} = 6”, R_{beam} = 1 cm, I_b = 2 kA, Risetime = 20 ns, *KE* = 12 MeV

$$V_{loop} = 0.57 \text{ V}$$

- A 3-turn loop signal would be > 1.5 V
- For comparison, a BPM20 detector signal is less than 0.3 V

The details of loop construction is important to achieve balanced signal output immune to common-mode backgrounds.

- **Common mode signals include direct charge pickup, high-voltage coupling, cable Comptons, ground loops, etc.**

- **Balanced B-dot pickup loops provide a degree of immunity to common mode noise and backgrounds.**
- **The raw signals from two equal area loops wound in opposite senses are differenced to eliminate common mode backgrounds:**

$$V_1 = +NA\frac{dB}{dt} + V_{common}$$
$$V_2 = -NA\frac{dB}{dt} + V_{common}$$
$$\therefore\ V_1 - V_2 = 2K\frac{dB}{dt}$$

- **Loop is wound with a twisted pair to ensure equal areas.**
- **Connected to coax feed-throughs in opposite senses.**
- **Connections made within a volume shielded against magnetic-flux pulse.**

Techniques for testing and calibrating diamagnetic loops were developed more than 15 years ago for DARHT diagnostics.

A fast-rising axial magnetic field for testing and calibration of diamagnetic loops is provided by a coaxial line with a spiral return, which is driven by a fast pulser.

Available Pulsers for Driving Calibration Line:

Short Pulse
- Northstar - 100 ns, 4 kV, < 15 ns risetime

Long Pulse
- Velonex – 2 μs, 1 kV, 150 – > 300 ns risetime
- Northstar – 2 μs, 7.5 kV, 100 ns risetime